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Soil sciences and the French 4 per 1000 Initiative—The promises of underground carbon

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ABSTRACT

The Paris Agreement reached at the COP 21 signals the new centrality of carbon sinks, including soils, as a key means of enabling a net zero carbon global balance through the development of 'negative emission technologies'. This article focuses on the 4 per 1000 Initiative, which the French government launched to foster soil carbon sequestration with an international scope. We present and discuss the multidisciplinary design of our research, the methodological tensions that it entailed and the assets that it eventually represented for a better consideration of soil agency and vulnerability. Drawing on an in-depth qualitative investigation, we discuss soil carbon sequestration promises in light of the broader politics of soil knowledge. We argue that the 4 per 1000 promise may have failed to give adequate attention to soil's complex agency (e.g. its capacity to both release and sequester carbon and other greenhouse gases) and soil's vulnerability (e.g. to urbanisation and intensive agriculture, which have long been causing soil degradation, including carbon loss). Committing to a richer conception of soil agency and soil fragility is crucial to enact the social and environmental conditions for fostering efficient and sustainable technological and political change in relation to climate change.

1. Introduction

Aiming to balance greenhouse gas emissions and the sequestering capacities of non-atmospheric sinks, the Paris Agreement reached at the COP 21 in 2015 signals the new centrality of carbon sinks, including soils, as a key means of enabling climate stability through the development of 'negative emission technologies' [1,2]. This article focuses on the interpellation and promotion of soils as an enhanced carbon sink that absorbs anthropogenic greenhouse gas emissions. It explores the current hopes and expectations put into soil carbon sequestration techniques, the problems of method in studying these expectations, and their significance for climate and soil policies.

Because soil holds about two times as much carbon as the atmosphere or the vegetation [3], it represents the largest terrestrial carbon sink over which we may have control. Soil carbon sequestration involves increasing the amount of carbon in the topsoil, i.e. the first layer of soil, which hosts most of soil life (usually about 30–40 cm deep) through land use changes (i.e. by privileging forests and pasture over crops and vineyards) and through adapted agricultural practices [4]. Soil carbon sequestration also increases soil fertility, as carbon (in the form of organic matter) aids plant growth [5,6]. Therefore, using soil as a sink through 'carbon farming' (i.e. using farming methods that reduce greenhouse gas emissions, and/or capture and hold carbon in vegetation and soils) is also intimately bound to the anticipated 'co-benefits' of improving soil fertility.

The hoped-for potential of such technologies accompanies the emergence of a highly speculative and promissory climatic regime that draws on collective expectations that technological development will make it possible to anticipate, mitigate, and adapt to climate change after previous attempts to decrease anthropogenic greenhouse gas emissions have stalled [7]. Most experts and scientists deem the 2 °C threshold to be unreachable unless the carbon sink capacities of oceans and/or soils are adequately exploited, thereby allowing additional time to implement the required transition toward a "decarbonized economy." To date, however, the social sciences have paid little attention to the cultural, political, and ecological significance of negative

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emission and other geoengineering technologies – in part because researching them was long viewed as contributing to shifting attention away from the much-needed abatement of greenhouse emissions [8]. While expectations regarding negative emission technologies have risen in the wake of the COP 21, most of these technologies, so far, rely largely on theoretical principles rather than on reliable technologies. Nonetheless, the hopes they generate have major socio-political implications as they foster a range of novel science policies, research and development agendas, organizations, and activities to try to come up with the expected solutions.

Our contribution develops a multidisciplinary and empirically grounded analysis of the recent "4 per 1000: Soils for Food Security and Climate" Initiative,[1] which the French government launched to foster and materialize soil carbon sequestration at a global scale. Initially inspired by a back-of-the envelop calculation that increasing the amount of carbon contained in soil by 0.4% per year would be sufficient to offset annual anthropogenic greenhouse gas emissions (published in a French-language, agricultural journal: [9]), the 4 per 1000 Initiative aims to mobilize resources, audiences, and allies to materialize the hoped-for futures of negative emission technologies, including new research on soil carbon, new carbon farming initiatives and organizations, and new technological artefacts (e.g. plant species capable of storing more carbon deeper in the soil). Importantly, under the future narratives offered by the Initiative, agriculture is turned into a major source of climate action and solution, also countering longstanding accusations of being a source of greenhouse gas emissions and environmental pollution (e.g. [10–12]).

By focusing on the early developments and reception of the 4 per 1000 Initiative – at a time when it was still new and highly debated among soil science and agronomy communities – this article primarily aims to contribute to a critical assessment of the current climatic governance regime's reliance on promissory techno-scientific developments that would make it possible to compensate for anthropogenic greenhouse gas emissions and 'adapt' agriculture and forestry to climate change, while escaping major immediate changes in our current model of economic growth and consumption [8]. Our investigation first shows how a small group of French scientists and policy-makers turned a 'back-of-the-envelope' calculation regarding soil, carbon, and climate change into a powerful promise of enhancing the carbon absorptive capacities of soils, which had the effect of fostering new research agendas, organizations, and activities relating to soil carbon monitoring, data, and modeling. Then we discuss soil carbon sequestration promises in light of the broader politics of soil knowledge. We account for the debates, tensions, and controversies both arising from and taking place *within* the soil science community regarding the feasibility of the 4 per 1000 promise. Relying on soil scientists' criticisms of the 4 per 1000 promise, we eventually call for a richer vision of the complexity and diversity of soil agency – including particularly the capacity of soil to both release and sequester carbon and other greenhouse gases. We argue that the 4 per 1000 promise relies on a rather restrictive vision of soil as a global stock of carbon that we could monitor, model, manage, and enhance, which largely downplays the actual complexity and diversity of soil agency as well as major pressing issues of soil conservation – which contributes to weakening the mere possibility of using soil as a sink.

2. Methodological and theoretical background

2.1. A qualitative investigation stemming from a multidisciplinary research setting: methods and problems

Our contribution stems from a multidisciplinary research project involving five social scientists and four soil scientists to address soil/society relationships.[2] Recent literature highlighted the need for environmental social sciences to focus more on social diversity and power issues [13,14], and massively addressed the benefits of interdisciplinary research to address and manage socio-ecological change (see for instance: [15,16]). While soil scientists themselves call for social scientists to engage much more substantively with soil (see for instance: [17]), recent literature in environmental social sciences symmetrically emphasized the need to take into account the physical materialities at stake in environmental issues through "doing more interdisciplinary, integrated socio-technical research that reflects the integrated nature of the physics and the social in these systems" ([18], p. 80). In line with these insights, the project was considered an opportunity both by soil scientists and social scientists to experiment with an open-ended and flexible multidisciplinary setting in which the research design and outputs remained mostly driven by social scientists' usual methods and approaches. On the other hand, soil scientists were particularly interested in understanding what they perceived as a lack of interest in soil and soil issues among the society at large and wanted to make soil and soil research more visible to decision-makers and the broader public. To them, the multidisciplinary research program was an opportunity to contribute to enhancing soil and soil science visibility and status.

While the investigation was initially designed with a very broad scope, without choosing one sector or policy relating to soil, during the course of the project it became clear that social scientists and soil scientists were favoring partly different research interests and methodological approaches. Soil scientists wanted the investigation to encompass the various socio-economic sectors and activities involving soil (including agriculture, land planning, urbanism, mining, nature conservation, climate policy etc…) because they were interested in learning more about soil and soil science understandings in society at large, while social scientists were privileging a more restrained framing of one 'angle' to studying soil/society relations and one specific soil-related sector or policy. Social scientists and soil scientists also had different views of the scope of data collecting, with soil scientists tending to plan a high number of interviews in order to collect as much data as possible, and social scientists being concerned over the time needed to exploit all the interviews together with the rest of the collected information in a thorough manner, fearing that we may all eventually be 'lost' in too much information and data.

As soil and climate linkages seemed to be a crucial and timely topic to the whole research group, we decided that the 4 per 1000 Initiative was an opportunity to develop a more restrained and specific focus on soil and climate policies. This meant that we had to adjust the collection of data to that new focus in the course of the investigation, both by retrieving information pertaining to soil carbon sequestration from the broad set of data initially collected, and by collecting complementary information through dedicated websites and a few additional interviews on the 4 per 1000 Initiative.

Our qualitative investigation brought together various types of data, including seven semi-direct interviews (each running about 1.5 h) with soil scientists and officials from the Agriculture Ministry and the French Agency for Environment and Energy Management (ADEME) involved in the origins and implementation of the Initiative; governmental and non-governmental websites and reports related to the 4 per 1000 Initiative; and the use of the mail archives of the French Association for the Study of Soil (AFES). The AFES has 500 members and 1559 subscribers, including scientists, students, consultants, farmers, and practitioners interested in soil. These archives confirmed that the 4 per 1000 Initiative has been a "hot", controversial topic among soil experts and practitioners since its launch in 2015. We also made use of the recorded

[1] https://www.4p1000.org/.

[2] This project was funded by Labex ITEM through a program dedicated to fostering interdisciplinary collaboration on human/environment relations. Multidisciplinary exchanges included the joint writing of this article among a social scientist, a soil scientist, and the two master's degree students who realized a large part of the field work under interdisciplinary co-supervision.

conferences of key players in the Initiative, including French Minister of Agriculture Stéphane Le Foll, which are available on the Internet. In addition, we relied on 40 more interviews with soil researchers, decision-makers, activists, and stakeholders that were conducted within the initially broader focus of our field-work. Those interviews included questions about the interviewees' visions of the 4 per 1000 Initiative and allowed us to get a better understanding of the Initiative's broader context and reception. In particular, the soil scientists we interviewed provided precious insights into the ways in which the Initiative has had an impact on their research field and into the pending questions, uncertainties, and debates around soil carbon sequestration. Those data were backed up with the reading of soil science research articles, which allowed for a more extensive picture of the international soil research community's position on soil carbon sequestration.

Overall, we think that the methodological tension stemming from the multidisciplinary setting of our research eventually allowed for a better consideration of how soil 'matters', even though it also made it challenging for the social scientists involved in the project to answer classical disciplinary questions regarding their specific approach and 'angle' – meaning which specific policy, activity, or issue in relation to soil they had chosen to study. In addition, the initial open-ended design of the research allowed for collecting a broad range of views and examples regarding the importance of soil for diverse social activities and the need for paying more attention to soil conservation issues in those various sectors, which helped us develop broader critical insights into the specific hopes raised by using soil as enhanced carbon sink.

In particular, the involvement of soil scientists in the project was instrumental both for identifying and accessing interviewees (for instance leading to some official leaders from the 4 per 1000 Initiative accepting to be interviewed despite their busy schedules) and collecting key information, and for capturing the internal ambiguities of soil scientists regarding the Initiative. While soil carbon sequestration represented indeed a major opportunity to enhance the status of soil science, it also fostered and exacerbated cleavages and tensions among soil scientists' different epistemological and political commitments. The multidisciplinary collaboration acted as an ongoing interview with the soil scientists participating in the research, allowing for a deeper immersion in the topic and the issues at stake. Importantly, the multidisciplinary design of our research contributed to focusing the analysis not only on humans and socio-political strategies but also on soil processes and agencies that are crucial to the success of negative emission technologies.

2.2. Theoretical background: sociology of promises and the politics of soil knowledge

We argue that developing a global reliance on soil carbon sequestration requires unpacking the socio-political implications of current sequestration promises, at stake for instance in the 4 per 1000 Initiative. Key to the research of scholars in the field of the sociology of promises and expectations is the idea that promises do not merely consist of discursive depictions of a possible future; they also have the power to foster effective present changes leading to the production of a new present reality [19–24]. Recent scholarship at the intersection of science and innovation studies, critical social theory and future studies also highlighted the significance of various future-oriented and anticipatory visions and practices in shaping present agendas and activities (see for instance: [25–27]). In line with this scholarship, our contribution discusses soil carbon sequestration promises in light of the current debates, questions and tensions constitutive of the politics of soil knowledge in a time of global change. We locate these promises within a series of key issues of the contemporary politics of soil knowledge which are both at play between soil sciences and other disciplines and fields, and inside soil sciences in relation to internal debates and controversies regarding which soil science is 'worth doing' [28].

Our discussion of the politics of soil knowledge is threefold:

(i) we document the partial reorientation of soil science agendas and activities toward soil carbon sequestration and climate issues as part of a broader "strategic climatisation" of soil sciences agendas and activities [29]: while soil sciences have long been attracting much less funding, jobs and general support than climate sciences, a number of soil scientists now tend to promote new linkages between soil and climate issues in order to get some of the resources and audiences that go to global change sciences.
(ii) we found that the 4 per 1000 Initiative not only fostered the creation of new agendas, opportunities, and resources for soil science around the promise of using soil as a carbon sink but also challenged and disrupted previous agendas, alliances, and networks *within* the soil science community; we unpack soil science internal tensions and debates regarding the proper way of knowing soil and soil carbon through competing research agendas, practices and goals (for instance through developing in-depth, situated field-work or relying on big data surveys and general modeling) and we account for the tensions regarding soil carbon stability over time.
(iii) we highlight the need for interdisciplinary soil research involving both physical and social scientists in order to achieve a richer conception of soil agencies (by which we primarily mean soils' capacity to both release and sequester carbon and other greenhouse gases). In recognizing that we need to meet the "new pressure for the social sciences and humanities to engage substantively with scientific findings – to move through critique toward dialogue and collaboration" identified by sociologist Nigel Clark in his research on and with the earth sciences ([30], p. x), we call for a better consideration of the major pressing issues of soil conservation as prerequisites for developing the hoped-for political and technical changes involved in soil carbon sequestration. By calling for a richer conception of soil agencies, we also hope to help perform the socio-environmental conditions for fostering efficient political and technological change in the context of the current environmental and climate crisis.

3. The origin and launch of the 4 per 1000 Initiative

Launched by the French government during the COP 21 as a voluntary action plan under the Lima Paris Agenda for Action, the 4 per 1000 Initiative comprises a research program, as well as a few research case studies and pilot projects whose aim is to elaborate the technological and organizational prerequisites to engineer climate-smart soils in a broad range of national and local contexts. The Initiative currently has more than 200 international signatories, including 40 countries as well as agricultural organizations, NGOs and companies. It attracts increasing interest within soil science international community (see for instance the international symposium "Soil Organic Matter Management in Agriculture – assessing of the 4 per 1000 Initiative the potential" organized in Germany in May 2018[3]). Various similar national initiatives have been launched in Australia and the United-States aiming to foster carbon sequestration within soil through adapted land uses and agricultural practices; activist organizations promoting carbon farming are also developing in England and the United States.[4] Hence our focus on the 4 per 1000 does not pertain to France only: instead, it

[3] https://www.som-management.org/.

[4] See the development of carbon farming national programs and initiatives in Australia (since 2011) and in California (since 2013: https://www.newsdeeply.com/water/articles/2017/07/31/carbon-farming-california-focus-on-soil-to-meet-climate-water-goals); and activist initiatives in England and the United-States in relation to North American scholar Eric Toensmeier's writings and interventions on carbon farming: https://www.farmcarbontoolkit.org.uk/carbon-farming-positive-change-ground; http://carbonfarmingsolution.com/bio; soil carbon sequestration is part of several solutions promoted by the international Drawdown coalition: http://www.drawdown.org/solutions.

allows us to offer insights into the evolution of global climate change strategies and policies as well as shifting soil/society relations related to soil carbon sequestration in a broader context.

In this first part, we first locate the Initiative within the recent history of the research on soil, carbon and climate change since the 1980s and emphasize the hopes placed in the potential of using biochar to sequester carbon within agricultural soils in the mid 2000s, that have broadly failed to deliver their promises so far. Then we present the origin and breakthrough of the 4 per 1000 Initiative, showing how the Initiative acted as an important means to mobilize and coordinate audiences and resources. Here we account for three sets of conditions that contributed to the success of the 4 per 1000 Initiative in the wake of the COP 21, i.e. the professional identity and position of the Initiative's promoters, the social and political context of the COP 21, and the use of the '4 per 1000' motto.

3.1. Historical insights into soil, carbon and climate research

While research on soil organic matter under various climates has long been conducted in the perspective of improving soil fertility and agricultural productivity, the question of soils' capacity for carbon sequestration acquired a new significance in light of climate change assessments and policies since the beginning of the 1990s [31]. Indeed, soil scientists such as Rattan Lal, at Ohio University in the United-States, or John M. Kimble, at the United-States Department of Agriculture, who both later became leading scientists on using soil as carbon sink in climate change mitigation strategies, were previously studying the links between soil organic matter and soil fertility under various climates [32]. Since the beginning of the 1990s, much scientific attention has been to studying how soil carbon stocks would evolve under changing climates, given that there is a complex balance between increased organic matter decomposition rates due to warmer temperatures (i.e. increased carbon release from soils to the atmosphere through soil organisms' respiration) and increased photosynthesis rate due to higher atmospheric concentrations in CO_2 (i.e. increased vegetation biomass leading to higher soil carbon inputs as dead organic matter) – with no clear-cut general answer to the question of knowing whether soil would eventually contribute to 'solving' climate change or instead aggravating it [3].

A first international consortium, the soil organic matter network (SOMNET), emerged in the 1990s. It was funded by the Global Change and Terrestrial Ecosystems project (a core project of the International Geosphere-Biosphere Program) and included modelers and scientists producing long-term observational data on soil organic matter dynamics. This pioneering research network on soil organic matter then fueled the long term soil experiment (LTSE) network and the current international soil carbon network (ISCN[5]: [31]). Since the 1990s, the literature has both emphasized the risks of massive losses of carbon from the world's soils may aggravate CO_2 concentrations in the atmosphere, especially due to permafrost thaw, increased rates of decomposition in peatlands and conversion of natural vegetation to cropland, and the perks of using soil as a sink to mitigate CO_2 emissions [33,34]. The importance of better characterizing the relations between soil carbon and CO_2 concentrations in the atmosphere was put forward in the third assessment report of the IPCC, which emphasized that soil was the largest reservoir of carbon on Earth [35]. In the 2000s the idea of enriching soils with biochar – a carbon-rich substance that is formed when biomass is burned in certain conditions – attracted much research and development attention: as the carbon contained in biochar resists decomposition for a very long time, incorporating biochar into soils, especially African soils, was seen as a promising 'triple win' strategy that would improve soil fertility, alleviate rural poverty, and mitigate climate change [36]. Biochar scientists calculated that biochar soil management provided a global carbon sink larger than the annual quantity of carbon currently produced by fossil fuels (ibidem), raising much interest among policy circles interested in geo-engineering and 'negative emission technologies' [37]. The perspective was then to develop biochar production and use as part of the expansion of carbon markets, together with the emerging REDD+ mechanisms based on carbon sequestration in vegetation and forests [38]. However large-scale biochar production and use failed to materialize, both due to technical issues of feasibility related to the amount of land needed for large biomass plantations, to unresolved questions regarding carbon's longevity and measurement within soils and to heavy socio-political controversies on the risks of land grabbing disregarding the actual practices and livelihoods of rural inhabitants in the South.

The 4 per 1000 Initiative thus reactivates the perspective of carbon sequestration in soil and vegetation at stake with the former biochar initiatives and with the implementation of REDD[6] mechanisms in the case of forests – which failed to deliver their promises in both cases so far (see Foyer et al. [39] in the case of forests). While in the 2000s soil carbon sequestration was envisioned through the production and use of biochar in Southern countries, the 4 per 1000 Initiative focuses instead on adopting farming practices that return more organic matter to the soil, e.g. by avoiding bare soil and using cover crops, at the global level.

3.2. The breakthrough of the 4 per 1000 promise

According to Van Lente and Rip's seminal article [19], promises are successful when their promoters have adequate legitimacy to navigate between various social worlds and circulate ideas between academia and the policy arenas. This is true in the case of the 4 per 1000 Initiative, which has benefited from being promoted by particularly efficient "champions" both in the academic community (e.g. Dominique Arrouays) and, most importantly, in the political community (e.g. Minister Le Foll). Arrouays was one of the authors of a 1999 report that mentioned the notion of offsetting anthropogenic greenhouse gas emissions by increasing the global stock of carbon in soil by 0.4%. He is a soil researcher at the French National Research Institute for Agriculture (INRA), has coordinated a range of big research programs at the intersection between soil science, carbon research, and agronomy, and has been involved in various international and national science/policy interfaces on climate and soil, including the IPCC at the international level and AFES at the French level (he was president of the AFES between 2012 and 2015). Since 1999 he has been mentioning the 0.4% ratio in various international national conferences, yet it was only in 2015 that the idea of soil carbon sequestration really broke through. INRA organized a conference on soils for the 2015 Paris Salon of Agriculture, and at this conference, Minister Le Foll publicly declared:

> "I just noticed a figure that was brought to my attention on this piece of paper I have here. I don't know if you can confirm this, but I've been told by INRA that a relative annual increase of 4 per 1000 of soil organic matter stock would be enough to compensate for greenhouse gas emissions on earth. Conversely, a relative decrease of 4 per 1000 would double our emissions. […] I perfectly understand this calculation. I think it's part of the main topics [that we should urgently address]."[7]

According to one of the Initiative's scientific officers, "the soil community always tried [to promote the notion of soil carbon sequestration]: they always tried, but they never managed to 'break through.' Actually, I feel that it's because… […] It may be silly, but we needed… a star." France's Minister of Agriculture Le Foll, who has been a strong promoter of agroecology for several years, became indeed a prominent

[5] http://iscn.fluxdata.org/.

[6] « Reducing emissions from deforestation and forest degradation ».

[7] http://www.inra.fr/Chercheurs-etudiants/Dossiers/Les-rencontres-et-le-colloque-du-SIA-2015/Colloque-SIA-2015-les-sols/(key)/8. (last Accessed on 5 July 2017).

spokesperson of the idea that soils, provided they be correctly managed, could contribute to absorbing anthropogenic carbon away from the atmosphere.

While the 4 per 1000 idea initially came from soil and climate research (with the initial 1999 report), agronomists also started to adopt and promote the concept and its relevance for agricultural fertility and food security issues after Le Foll promoted the 4 per 1000 calculation at an international scientific conference on climate-smart agriculture in Montpellier, France, in March 2015. Integrating and emphasizing food security issues was critical to attract the support of agronomy research and national and international organizations concerned with agriculture and development in Southern countries. This was critical to give a broader scope and audience to the 4 per 1000 concept by setting up a bridge between issues that had previously been conceived and addressed separately, i.e. climate change mitigation, land degradation mitigation, food security, and Southern countries' development. From then on – as was the case with biochar – the Initiative was conceived of as a 'triple-win' solution contributing to mitigation, adaptation, and food security purposes.

At the COP 21, France presented the 4 per 1000 concept to the international community within a favorable context that provided a supportive "rhetorical space" for promoters of soil-based negative emission technologies [19]. At that time, issues of and concerns for soil were progressively gaining ground on international governmental and non-governmental agendas: following the launch of the Global Soil Partnership in 2011 and the publication of the revised Soil Charter by the Food and Agriculture Organization in 2015, the United Nations labeled 2015 the "International Year of Soils." The COP 21 negotiations concluded with an official agreement on the need to keep the average temperature increase below 2 °C (possibly 1.5 °C). On this occasion, many scientists and experts emphasized that the 2 °C threshold was unreachable unless oceans' and/or soils' carbon sink capacities were adequately exploited to buffer part, if not all, of our current greenhouse gas emissions, giving us extra time to implement the required transition toward a "decarbonized economy." The international environmental and climate community that gathered at the COP 21 was thus particularly receptive to soil-related negative emission technology proposals.

In addition, the bridge that the Initiative proposed to build between climate mitigation, agriculture, and Southern development was very timely in the context of COP 21 negotiations, which attested to the rising integration of development and humanitarian aid topics in the climatic regime [40]. While climate negotiations have been marked by longstanding critics from the South regarding the influence of the North in framing solutions to climate change, the 4 per 1000 proposed instead to bridge Northern and Southern interests and visions regarding climate policies. The fact that France could put forward the historical national importance of agriculture for the country and the historical action of France in Southern agricultural development also contributed to the successful reception of the 4 per 1000 proposal at the COP 21, where it was officially presented under the form of a research and action Initiative by Stéphane Le Foll and Laurence Tubiana, a French policy-maker who was then French ambassador for international climate negotiations.

Also in line with Van Lente and Rip's findings on the role of a label that can serve as a "currency" to communicate promises during public presentations and debates [19], the catchy '4 per 1000' motto helped the proposal to circulate and to break through among various audiences. Resulting from the subsequent rediscovery of the 1999 report, the 0.4% figure has the clarity and power of numbers [41] in the same way as the 2 °C target figure for climate negotiations. Beyond the simplicity of the message, the 4 per 1000 motto also has the advantage of sounding easily attainable: "Everybody adheres to it because it looks like a very tiny objective to reach. We're not asking for 10%… […] so everyone thinks 'Oh! It's nothing, really'," a representative from ADEME told us.

The combination of those ingredients explains why the promoters of the 4 per 1000 Initiative managed to gather signatures from 25 countries and a hundred organizations for a joint declaration at the end of the COP 21. One year later, at the COP 22 in Marrakesh, Morocco, the governance of the Initiative was established, including a forum, a consortium, decision-making bodies, and a Scientific and Technical Committee with international experts from a range of countries. An international research program was also implemented, orchestrated by INRA together with other French research institutions working in the fields of agriculture and development, the Consultative Group on International Agricultural Research (CGIAR), and with Ohio University, where American soil scientist Rattan Lal has been developing leading research on soil carbon sequestration for more than 15 years. Two job positions were created to coordinate the Initiative.

4. The politics of soil knowledge and the 4 per 1000 Initiative

4.1. Repositioning soil science within climate change research

Even though the 4 per 1000 Initiative does not directly fund any research project, the launch of the Initiative fostered new research and development agendas, activities, and groups focused on soil carbon measurement, monitoring, and modeling – in line with the analysis of the performativity of techno-scientific promises in terms of their "constitutive force" [22] or their "institutive power" [42]. In the beginning of 2017, the French Ministry of Agriculture and the National Agency for Environment and Energy commissioned a study to assess the technical and socio-economic feasibility of storing an additional 0.4% of carbon in French soils. A number of recent scientific articles have also published various assessments of the feasibility of implementing the 4 per 1000 Initiative, including some environmental and socio-economical aspects (e.g. [43–48]; etc.), and some recommendations for the development of a general framework for implementing "4 per 1000" projects [49].

The emergence of those research agendas and activities focusing on soil carbon should be understood in a context where soil science has long suffered from a general lack of interest, which eventually led to the gradual disappearance of a number of soil-related courses at the university level. The low status of soil science is in line with the long-standing decline of the status and resources of the field-based sciences compared with those of laboratory-based sciences since the end of the 19th century [50]. Like other field-based sciences, research on soil is time-consuming and provides few opportunities for fast publication [51]. Hartemink and McBratney [52] estimated that soil science was receiving less than 1% of the global R&D budget in the 2000s. Soil scientists were often deemed incapable of providing managers and decision-makers with quantitative and "ready-to-use" data because they were more interested in empirically documenting the contextualized characteristics and particular histories of local soils (ibidem). In addition, our interviewees and collaborators frequently emphasized the complex and invisible nature of soil and that the general ignorance with regard to soil was a critical impediment to attracting audiences and resources.

In this context, the breakthrough of the 4 per 1000 Initiative constituted an important opportunity for the soil science community to reposition itself within global change research hierarchies by re-affirming the importance of its research and fostering new linkages with climate issues and policies (i.e. through a "strategic climatisation" of soil sciences agendas and activities: [29]) as well as linkages with others international conventions and resolutions (e.g. United Nations sustainable development goals, convention to combat desertification), as explained by a scientific officer from the 4 per 1000 Initiative:

> "Personally, I instantly thought [the Initiative] was great. And I think everyone in the scientific community felt the same, at first… At least, for those interested in soil… saying: 'Oh! It's great! There's

something there, a buzz about soil, so it's time to be heard, now or never… The need for more research, the fact that we [soil scientists] can find solutions, that we need to put soil back on [the agenda]'…"

Stressing the potential of storing more carbon in soil has become a common communication strategy for soil researchers when applying for research grants: "It's been really fast, and it's true that it has almost become, now, a rhetorical exercise to mention the 4 per 1000 [Initiative] in our research projects," a soil microbiologist whom we interviewed told us.

Yet the soil science community might not be profiting in equal measure from the benefits brought by the Initiative. To date, research on soil carbon sequestration in France is mostly pursued by a few research teams and individuals whose agendas are strongly driven by the requirements of climate modeling, which are quite different from the type of in-depth field research on local soils and their contextual history that many soil scientists are committed to: "Climate people, they want general processes. […] whereas soil science uses models that are more empirical and field-based," a soil scientist explained to us. The French Laboratory of Climate Science and the Environment (LSCE), which hosts leading researchers on climate modeling, recently recruited a soil ecologist to integrate soil and soil life into global climate models. When we met this soil ecologist, he stressed that the new interest in soil carbon sequestration was a great opportunity for soil scientists but also a source of frustration when they realized that research on soil carbon was being carried out by climate scientists themselves instead of soil scientists:

"With all the IPCC programs and climate models, we realized that soils – I mean the soil-plant compartment – is a major compartment for climate models, both as a sink and a source. […] It was pretty funny because soil people told climate modelers: 'This is nonsense; we've known for over 50 years that this is the way soil carbon works!' It was interesting to see that frustration among soil people. Because the IPCC also gives access to a high factor impact index, etc. Soil people began to realize that soil had become a hot topic in the scientific sphere, but it was being researched by climatologists!"

He emphasized that climate-driven research on carbon cycles produced general models of carbon circulation that do not take into account the more local and contextualized knowledge of soil produced by many soil scientists. One soil scientist whom we interviewed explained that, while "generations of pedologists have been describing soils", current global climate models ignore the variability of soils: their running does not require any data from soil mapping, partly because the highly contextualized and empirically based knowledge of soil maps is very difficult to translate into more quantitative inputs for general carbon models.

4.2. Competing visions of which soil science matters

While soil carbon sequestration has certainly become a "very fashionable research topic" (according to a soil scientist involved in our research project), our fieldwork thus attests to the existence of an ongoing controversy among soil scientists regarding the type of research that soil science should commit to regarding soil carbon sequestration. Confirming that promissory innovations foster both the assemblage of new socio-technical networks and the dis-assemblage of previously existing networks and alliances [53], we found that the 4 per 1000 Initiative triggered, or sometimes exacerbated, a range of debates, tensions, and controversies both from and within the soil science community, regarding the type of research required to materialize soil carbon sequestration potential.[8]

On one hand, questions of soil carbon monitoring, mapping and assessing have attracted increasing research interest and investment in the wake of the 4 per 1000 Initiative, and soil scientists involved in the International Standardization Organization (ISO) argued that new standards for soil carbon assessment and monitoring need to be developed [54]. In a similar way, in the USA, scientists launched the International Soil Carbon Network whose goal is to develop accurate and global data on soil carbon and facilitate the synthesis of large-scale information on soil carbon [55]. This illustrates how a number of soil scientists think that the realization of soil carbon sequestration promises requires them to engage with quantitative and average soil data and global soil monitoring and modeling. On the other hand, this type of soil 'big data' research is at odds with the type of research that most soil scientists have been committed to, which addresses the contextual characteristics and history of local soils and relies on field observation rather than large sampling programs and big data modeling.

The article published by Minasny et al. in 2017 in *Geoderma,* one of the top ranking international journals in the field of soil sciences,[9] and the reactions it received from other soil scientists in the same journal are telling of these internal tensions. The article presents results from a meta-analysis of soil data in different countries using mathematical and statistical techniques in order to assess the potential of various soils for a 0.4% increase in carbon stocks. It was strongly criticized by a later article published by French soil biologist Baveye et al. [56] that promoted the importance of carefully controlled long-term field-based research on soils' contextual characteristics and evolution in order to answer fundamental questions on basic soil processes and feedbacks and to understand "the fate of organic (and inorganic!) carbon in soils […], and microbial processes or clay-organic interactions". To Baveye and colleagues, the 4 per 1000 Initiative is biased toward applied research, including soil costly and large-scale monitoring, sampling programs and "big data" analysis, whose methodological basis is still being debated given that soil is a highly heterogeneous and situated milieu, to the detriment of fundamental research aimed at understanding soil processes. In their answer, Minasny et al. [57] reasserted the assets of sampling programs and big data exploitation.

Another point of contention within soil science community regards the mere feasibility of enhancing the absorptive capacities of soils in a durable manner, which also reveals different visions of which soil research agenda matters in relation to climate issues and policies. Even though promoters of the Initiative argue that it aims to give an aspirational goal rather than any quantitative objective [57], some soil researchers, including those collaborating on our research, insistently recalled that no currently available technology is able to measure a 0.4% variation in soil carbon stocks. For them, the lack of measuring technologies seriously hampers the credibility and the fulfillment of the promise. This is why, in France, a number of soil scientists interested in the 4 per 1000 Initiative decided to create CarboSMS, a research network dedicated to researching soil carbon and carbon stabilization mechanisms. To date, the network has brought together 120 scientists from various French research institutes (INRA, CNRS – French National Center for Scientific Research –, IRD – Institute of Research on Development –, universities…) and particularly focused on assessing the challenges of stabilizing soil carbon stocks [4] and the various potentials of different soils to store carbon in a durable manner ([58]; see also [45]).

The exchanges on the AFES mailing list attest to the existence of a broader cleavage between scientists committed to publicly advocating for the 4 per 1000 promise and scientists promoting a neutral or non-committal attitude instead. Among the latter, a pedologist we interviewed stressed that "the political phase [of the 4 per 1000 Initiative]

[8] Those tensions were not apparent within our research team, in which soil scientists shared some degree of skepticism and doubt regarding the feasibility of the Initiative.

[9] With an impact factor of about 4 and a broad, interdisciplinary editorial scope in relation to soil, *Geoderma* is a highly recognized journal among soil scientists. It has been publishing many papers related to 'pedometrics' (i.e. soil big data and global mapping) since the beginning of 2010s.

has started, although I'd say the scientific phase is not mature enough." Scientists' fears of committing to a misleading promise particularly focused on the issue of soil carbon stability over time. Carbon cycle entails indeed soil acting both as a sink absorbing atmospheric carbon (through organic matter coming from plant photosynthesis) and as a source of carbon release (through soil organisms' respiration). The net amount of carbon sequestered in soil at a given moment results from the temporary difference between carbon inputs and outputs. As outlined by a soil biogeochemist participating in our project, an annual increase of 0.4% is only possible over a finite period of time. Beyond that period, the soil will no longer sequester carbon, instead it will reach a new equilibrium. The net amount of carbon may then even decrease if carbon inputs into the soil are not maintained [48]. Soil science research has long emphasized that "the storage of CO_2 in terrestrial carbon stocks is relatively volatile and subject to re-emission into the atmosphere" ([59]: 129). The same soil biogeochemist emphasized this duality:

> "We want to store more carbon in the soil, but soil biodiversity decomposes this carbon and releases it as CO_2, so we need to find a balance (…) without having massive releases of carbon into the atmosphere."

This recalls the "soil carbon dilemma" discussed by H. H. Janzen in the following terms: "We say we want to store more organic C; we say that it will make the atmosphere cooler and the soil better. But organic matter is most beneficial, biologically, as it dissipates by microbial activity." ([60]: 421).

Soil sciences have shown that the permanence of organic carbon below ground is dependent on soil properties [61], raising serious challenges for the feasibility of soil carbon storage techniques in various types of soil:

> "We realized that in certain soils only a very low proportion of carbon is stable. […] And in another kind of soil, right next to the former, in the same forest but with different pedological characteristics, a high proportion of carbon has remained below ground for over a century. […] And this leads us to the question of climate regulation: (…) we need to quantify the practices that allow for the storing of carbon over the long term, over time." (a soil biogeochemist who participates in our research project)

Accordingly, adopting agricultural practices that store more carbon below ground may be relevant only where soils are able to store the carbon in a durable manner over time. In a broader context, Chabbi et al. [44] emphasized the "need to identify soils and agro-ecosystems most suitable to increase SOC sequestration and quantify the economic benefits of additional C storage for different soil types, climate zones, production systems and farming capabilities, beyond C credits".

Yet political and media discourses around the 4 per 1000 Initiative have tended to ignore the fact that soil can contribute to both aggravating and 'solving' climate change issues. The presentation of the 4 per 1000 Initiative initially stressed that "a relative decrease of 4 per 1000 would double our emissions".[7] However, further discourses tended to erase the notion that soil may contribute to releasing carbon instead of storing it. Carbon storage only represents indeed one step in a dynamic cycle of carbon in the biosphere. The emphasis that the 4 per 1000 promise puts on soil acting as a carbon sink rather than a carbon source is well in line with [68] observation that soil is most often presented as a timeless and enduring "box" in which we may bury any waste we want to get rid of (see also [62]): "in contrast to the assumed instability and impermanence of social worlds aboveground, the subterranean is read as independent of social and political changes unfolding upon the surface, offering a band of stability and permanence across an almost unimaginable time horizon" ([68]: 17).

In particular, the 4 per 1000 calculation did not account for potential negative feedback loops in carbon cycle due to 'priming effect', which occurs when carbon is added to soil and results in the destabilization of the previously stored carbon and causes an increase in soil carbon emissions. Further, CO_2 is the only greenhouse gas considered by the 4 per 1000 Initiative, while agriculture also has a major influence on the atmospheric concentration of other powerful greenhouse gases, such as N_2O and CH_4 (but see [48,49]).

4.3. On soil agency and vulnerability

The debate on carbon stabilization and durability in soils is far from being merely a technical question, as soils have mostly been acting as a net source of carbon since the beginning of industrialized agriculture [63]. Agriculture has been responsible for soil depletion through a steady loss of nutrients, including carbon, since the end of the 19th century [64].

In this context, betting on soil-based negative emission technologies to mitigate climate change and address food security problems may sounds like a paradox. A soil scientist involved in our research project – echoing other soil scientists whom we met – recalled that the primary challenge for soil policies and practices may not be that of storing more carbon but instead that of stopping the release of the carbon currently contained in soils because of various forms of soil overexploitation:

> "Let's say, if we overexploit our soils, for instance, it would double anthropic emissions, so it's something big. This means that somewhere, there is this issue… The capital that soil carbon represents, we firstly need to maintain it, and not to deplete it, because potentially we would double our greenhouse gas emissions."

Several interviewees recalled that using soil as a carbon sink requires paying more attention to soil conservation and protecting soil against the constant threats of agricultural intensification, urbanization, and pollution. As a promoter of the 4 per 1000 stated in a message sent to the AFES mailing list in 2015, the "main objective for the COP 21 [was] to foster a slowdown in soil destruction in terms of quantity, quality, and functioning," but eventually that objective remained in the background of the development of the Initiative, which instead tended to take soil conservation for granted and to promote soil functioning as a ready-to-use 'fix' for greenhouse gas emissions. A soil scientist in charge of the Initiative also told us:

> "One of the remarks and one of the perils people often outline about the Initiative is that… by putting such a strong emphasis on soil and by selling it as a magic cure, if this cure is not rapidly implemented… and it won't be implemented rapidly, there's a risk that we'll be seen as crooks."

Soil scientists' fears of being considered as "crooks" were increased by biochar promises flagged by some soil scientists, which eventually proved to be unrealistic, as explained by a soil biologist in a message sent to AFES:

> "One of the reasons I am particularly wary is that, to a certain extent, this discussion takes me back 15 years. […] Johannes Lehmann had just written articles to promote the idea that burrowing biochar in soils was 'the' solution to climate change. […] Fifteen years later, the research on biochar is still stumbling along. We don't know exactly where it is at, but in any case, it is far – very far – from the perspectives that we initially presented. I reckon that soil science has not emerged unscathed from this saga."

In the AFES mail exchanges, one soil scientist involved in the initial calculation of the 0.4% ratio criticized the 4 per 1000 Initiative for "not taking soil sealing into consideration" – meaning that the volumes of soil capable of storing carbon are actually decreasing on the planetary scale, while the emissions caused by soil degradation and overexploitation are increasing. Baveye et al. [56] also stressed the need to develop awareness of the numerous services that soils provide, including the need to conserve them all, instead of merely focusing on soil capacities for carbon sequestration. This is in line with broader calls for

developing interdisciplinary approaches to soil and soil issues, likely to take into account the socio-political and economic dimensions and interdependencies of soil processes [17].

In addition, a range of soil scientists who expected that the new reliance of climate politics on using soil as sink would foster more consideration of soil issues and soil conservation criticized the Initiative for not clearly promoting any agro-ecological model likely to offer a clear alternative to the dominant model of agro-industry and its deleterious effects on soil depletion and erosion. While the Initiative's official website claims to "federate" agroecology and conservation agriculture,[10] the attempt to gather as much support and as big an audience as possible eventually led to the reference to alternative ecological agricultural models being downplayed. A soil scientist in charge of the Initiative whom we interviewed explained to us that the Initiative was meant to remain open-ended regarding the type of agriculture likely to foster soil carbon sequestration: "As for the message we want to send… we don't want to be the judge of… 'This agriculture is bad; this system is…'". While this strategy may have allowed for the 'recruitment' of a wider range of support, it also resulted in discouraging certain groups promoting a more ecological agriculture to join the Initiative, such as two French NGOs (i.e. CCFD-Terre Solidaire and Action contre la Faim), which criticized the Initiative because of the lack of a clear-cut position regarding agricultural models: "a list of concepts ranging from agroecology to conservation agriculture allegedly frames the activities, in spite of a blatant risk of instrumentalization. Any actor – from farming groups to agribusiness multinational firms – can find its niche."[11]

Those debates and tensions do not merely address the technical feasibility of using soils as carbon sink for climate change mitigation and food security: they are also part of the politics of soil and soil knowledge characterized by various and partly conflicting views of which soil knowledge matters in relation to climate change and environmental sustainability:

- monitoring, mapping and modeling soil carbon stocks and dynamics ('pedometrics') versus observing and experimenting on soil basic processes;
- focusing on soil carbon stocks only versus engaging with soil carbon dynamics (carbon storage and decay) and more broadly with soils multi-functionality, complexity and vulnerability.

5. Conclusion

Our analysis examined the international 4 per 1000 Initiative as part of a new, highly speculative and promissory climatic regime that increasingly relies on the hoped-for enactment of negative emission technologies. We showed how a small group of French scientists and policy-makers turned a back-of-the-envelope calculation regarding soil, carbon, and climate change into a powerful promise of using soil as a sink for climate change mitigation, with the effect of fostering new research agendas, organizations, and activities relating to soil carbon monitoring, data, and modeling, as well as new tensions and controversies regarding which type of soil research should be prioritized. While many soil scientists consider the Initiative a major opportunity to reaffirm the scientific and social relevance of researching soil, a number of them are also skeptical of the possibility of storing more carbon underground in a stable and durable manner, also given the lack of broader soil conservation policies.

Unpacking those critics and tensions allowed us to argue that soil carbon sequestration discourses and promises have failed to give adequate attention to soil's complex agency (i.e. its capacity to both release and sequester carbon and other greenhouse gases) and soil's vulnerability (e.g. to a range of anthropogenic activities, including urbanisation and intensive agriculture – which has long been causing soil carbon loss). Developing a global reliance on soil carbon sequestration and a richer vision of soil complex agencies and vulnerability requires taking position for a more precautionary and interdisciplinary politics of soil knowledge in a time of Anthropocene.

In that matter, the multidisciplinary setting of our research proved critical for a better consideration of soil agency and vulnerability and how they challenge the hopes and promises related to the 4 per 1000 Initiative. Adjusting to the multi-disciplinary design over the course of our research project was methodologically challenging as it fostered an investigation composed of an initial, open-ended step and a second step focused on soil carbon sequestration, which eventually proved fruitful for developing critical insights into the hopes arising from those techniques. Accepting the tension – instead of resolving it by choosing a specific sociological angle to soil/society relations from the start – initiated an experimental repositioning from social sciences' approach to scrutinizing *what people do and say* in relation to soil, to a dialogue *with* them in ways that allow us to consider soils' critical, and endangered, contribution to shaping future socio-ecologies. As such, we are very much in line with Germain Meulemans's account of his own research shift from unpacking the social manufacture of soil-related knowledge and innovation, to an "attentive attention" to soils themselves in order to "open up questions of what soils are" ([65], p. 22). We argue that this experiment was made possible by 'living with' and adjusting to the methodological tensions inherent to the collaboration between social and soil scientists.

As a result, the emphasis that we put on soil agency and vulnerability is not only part of a critical analysis of the socio-political 'hype' fostered by the 4 per 1000 Initiative [21], as a confirmation and contribution to the sociology of expectation scholarship; nor is our contribution only about emphasizing that soil is an 'actant' resisting or mediating the deployment of socio-technical innovation networks [66]. Rather, by highlighting the capacity of soils to foster unexpected and dystopian scenarios of carbon release and climate change aggravation – instead of the hoped-for futures of soil-based mitigation techniques – our hope is to contribute to a better consideration, in the social study of climate change and socio-ecological transitions, of the active capacities of non-humans (animals, plants, things, matter and ecological and physical forces) to foster 'more-than-human' or even 'inhuman' futures [30]. We argue that experimenting with multi-disciplinary research involving social and environmental scientists may help escape, at least partly, the patterns of the social construction of reality by "placing ourselves in between – at the fuzzy, impure, and shifting juncture where the construction of social meanings and promises is confronted with the world's own activity and has to accommodate its autonomous agency" ([67], p. xxii). Future developments in soil carbon sequestration clearly require sustained joint attention from social and soil scientists in order to do justice to the complexity of the socio-environmental challenges involved in negative emission technologies – and to help materialize the conditions for developing them in an efficient and sustainable way.

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